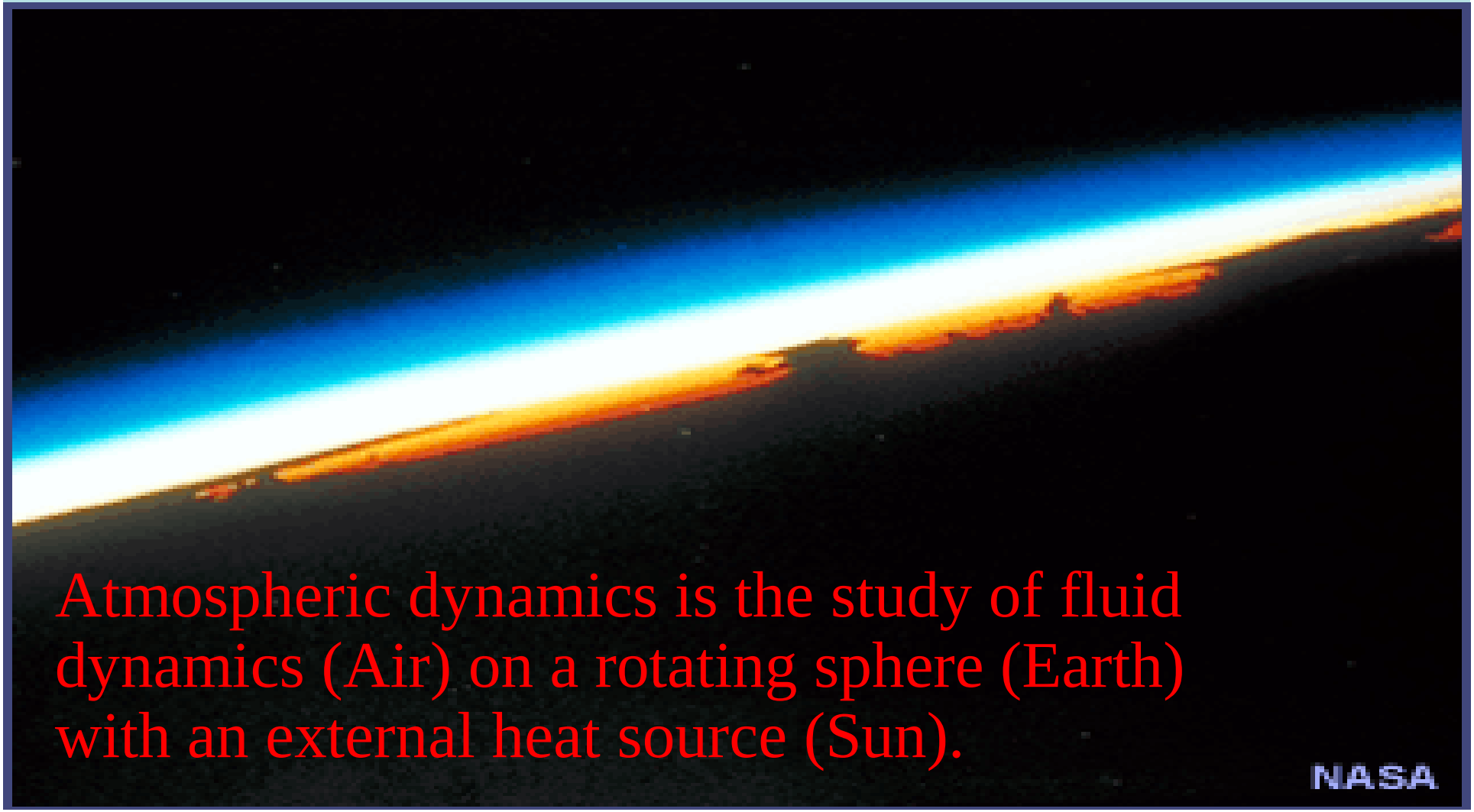
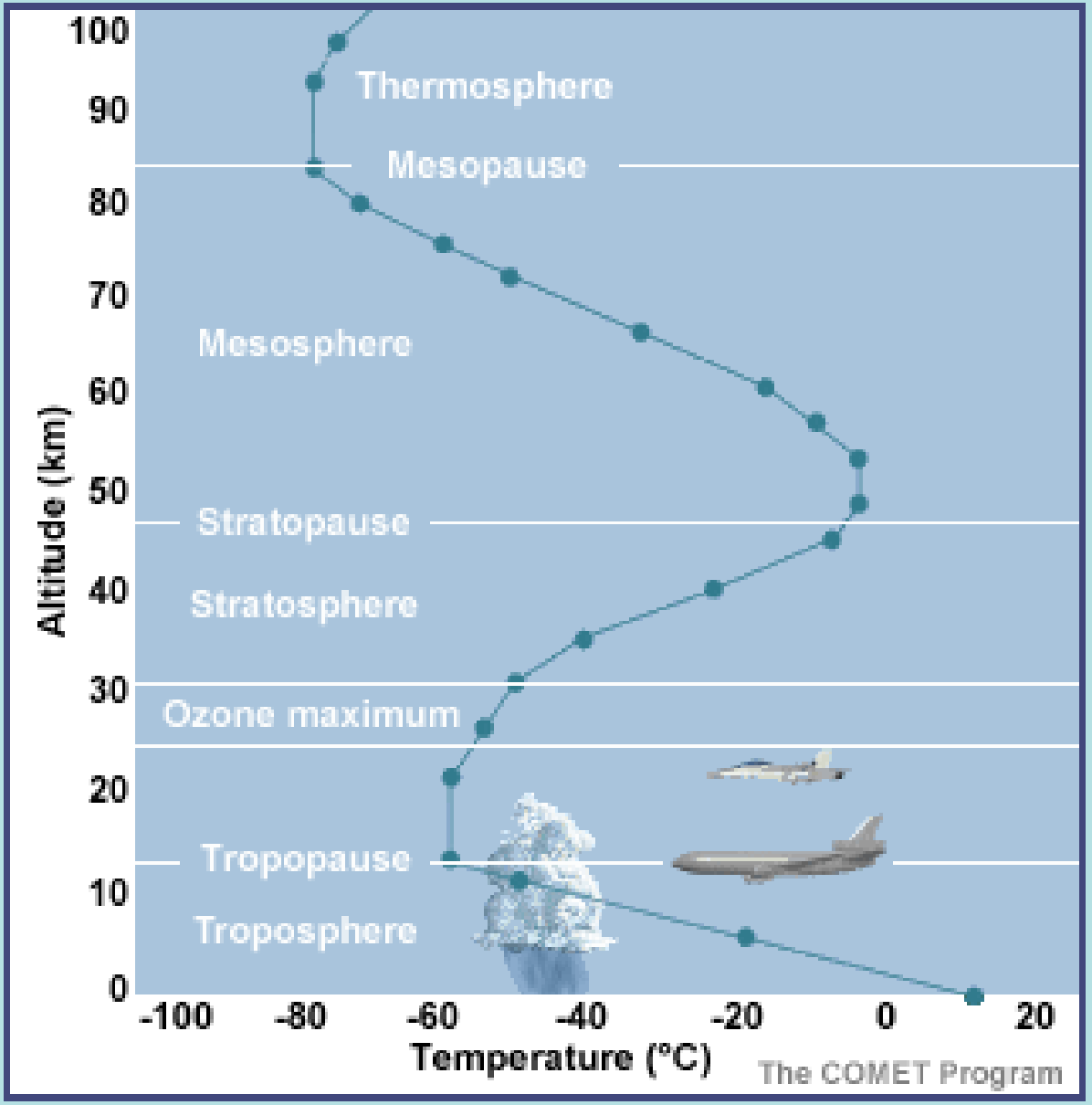
Atmospheric Dynamics and Transport

R. Bradley Pierce, NASA LaRC



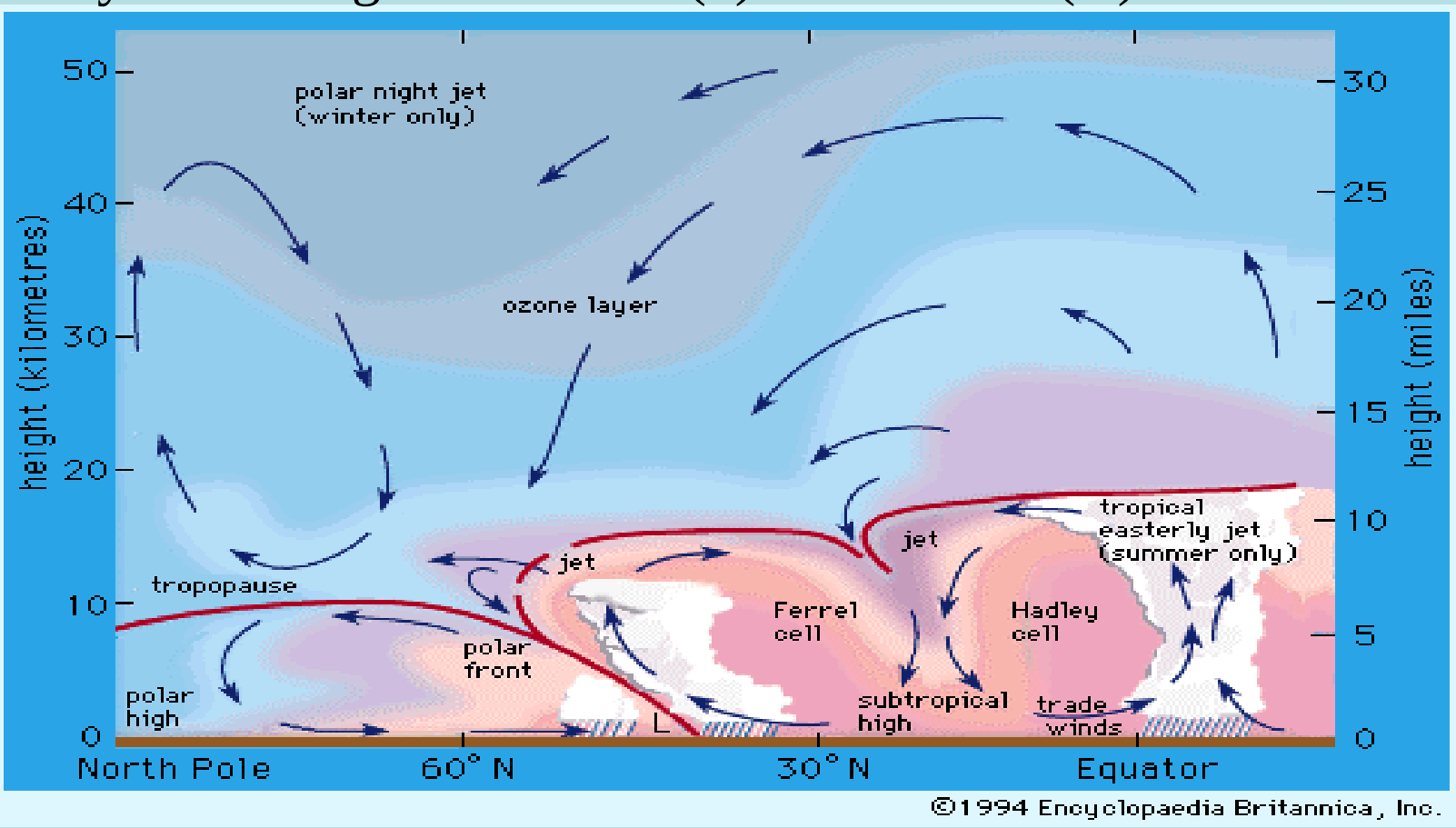
Vertical Structure

The Earth's atmosphere is divided into different regions based on the temperature lapse rate (variation of temperature with altitude). 90% of the mass of the atmosphere is below ~12km.



Atmospheric Circulation Patterns

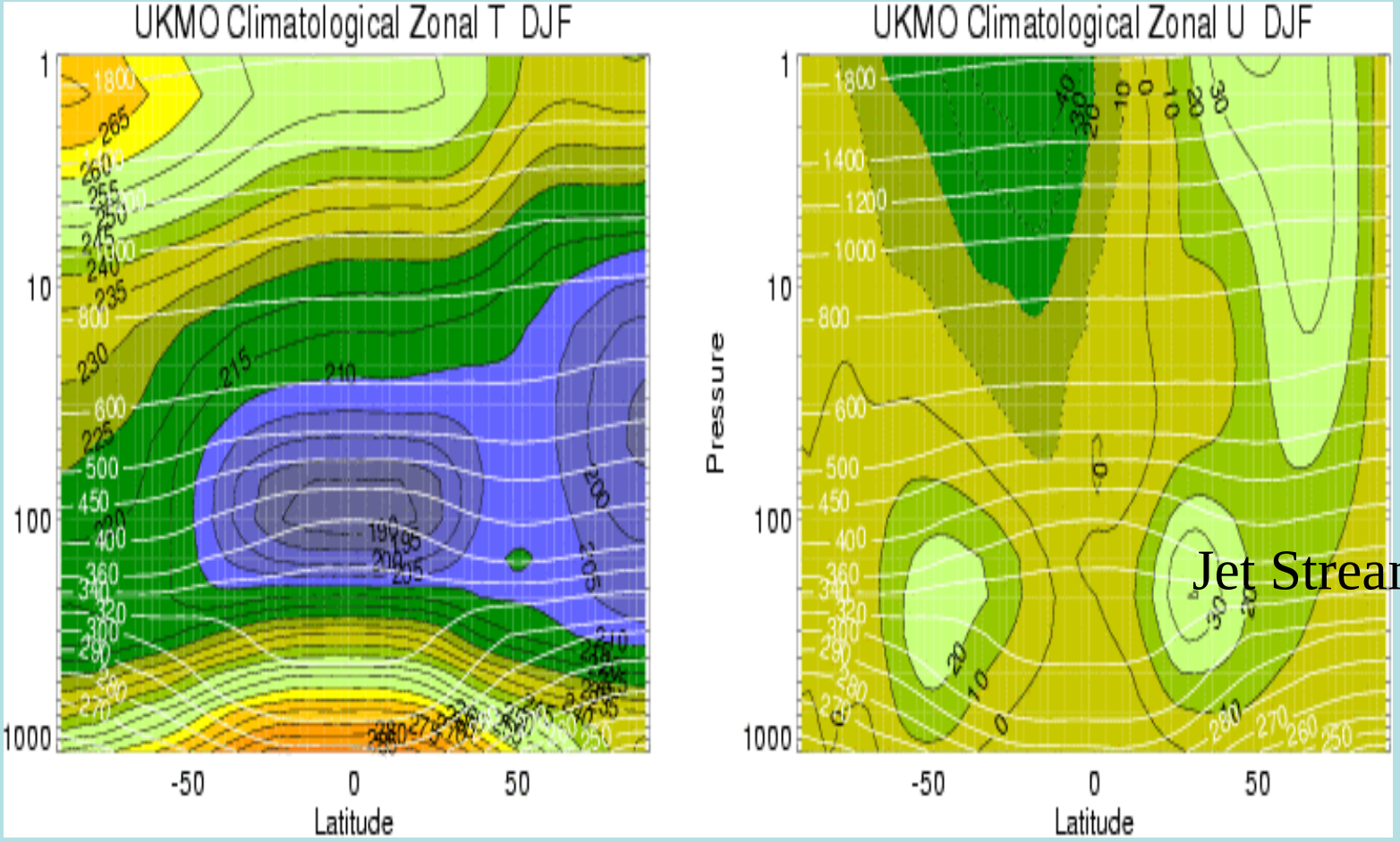
The atmospheric "zonal mean" circulation is determined by the average meridional (v) and vertical (w) winds.



The tropospheric meridional circulation is very fast (order of weeks) while the stratospheric circulation is very slow (order of years).

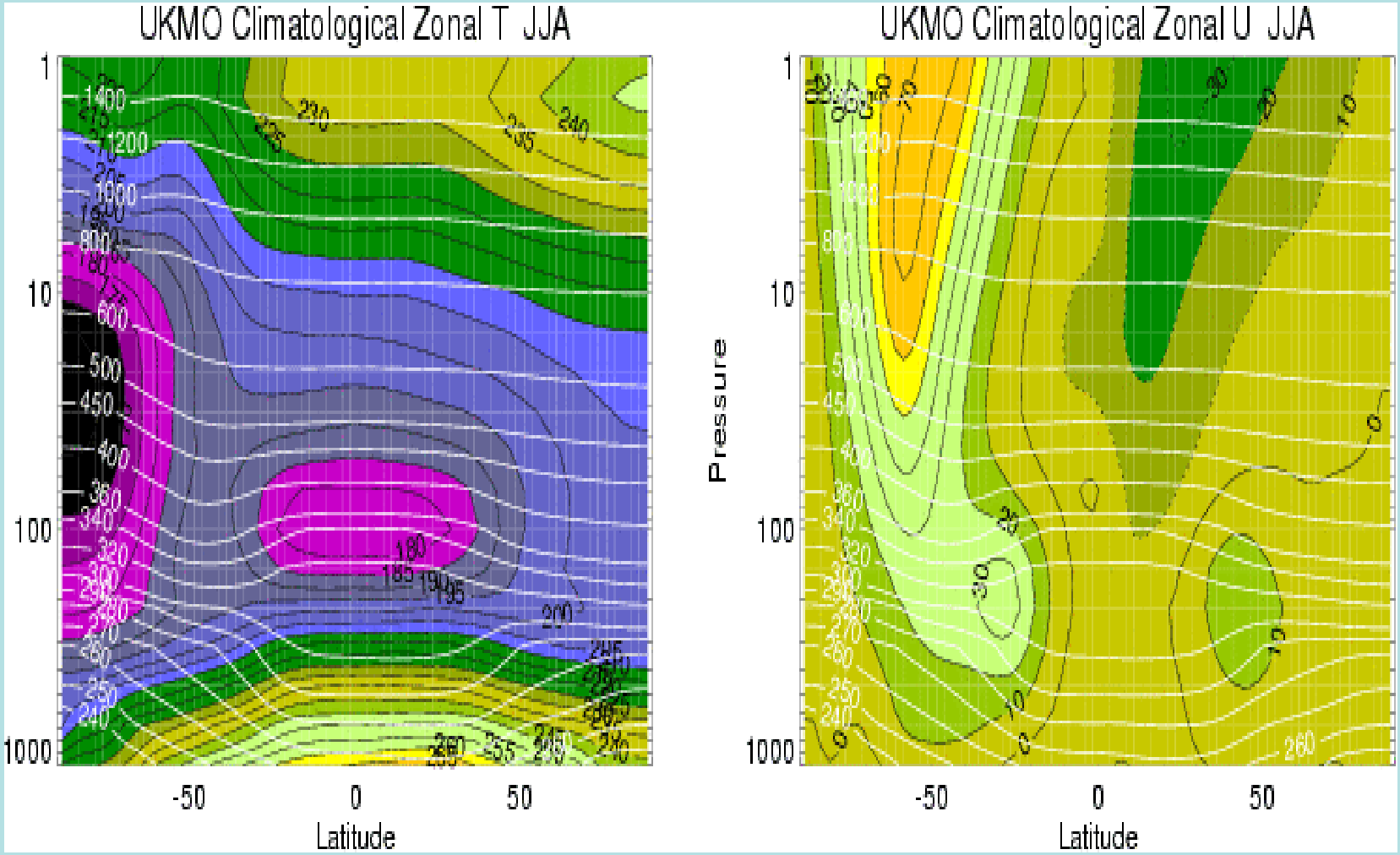
Zonally Averaged NH Winter Dynamics:

Data: United Kingdom Meteorological Office (UKMO) Analysis for the NASA Upper Atmospheric Research Satellite



The NH winter (DJF=Dec/Jan/Feb) circulation is characterized by strong westerly jets (the polar night jet and subtropical jet) and cold pole.

Zonally Averaged NH Summer Dynamics

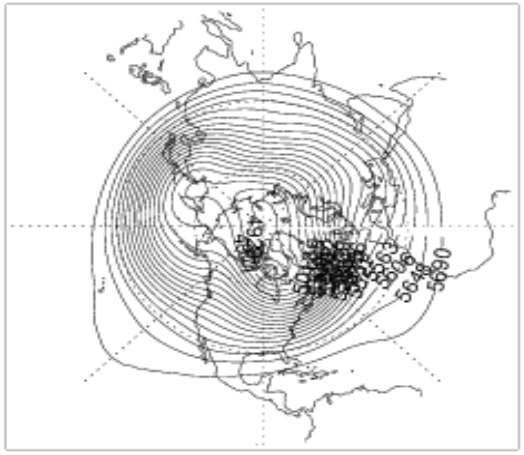


The NH summer (JJA=Jun/Jul/Aug) circulation is characterized by stratospheric easterlies and a warm pole.

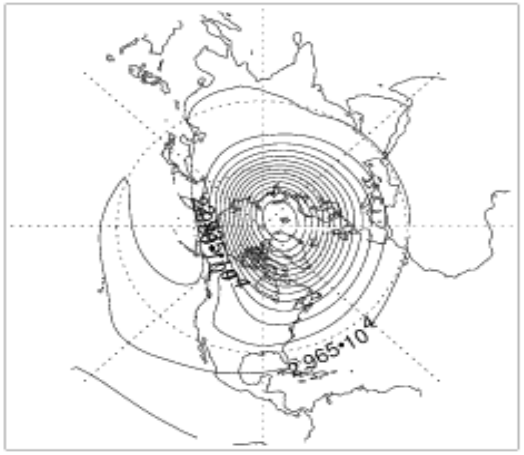
NH Winter Stationary Wave Patterns

Longitudinal variations in atmospheric circulation patterns are analyzed by looking at the variation of altitude (Height) on a pressure surface.

UKMO DJF 500mb Climatological Heights



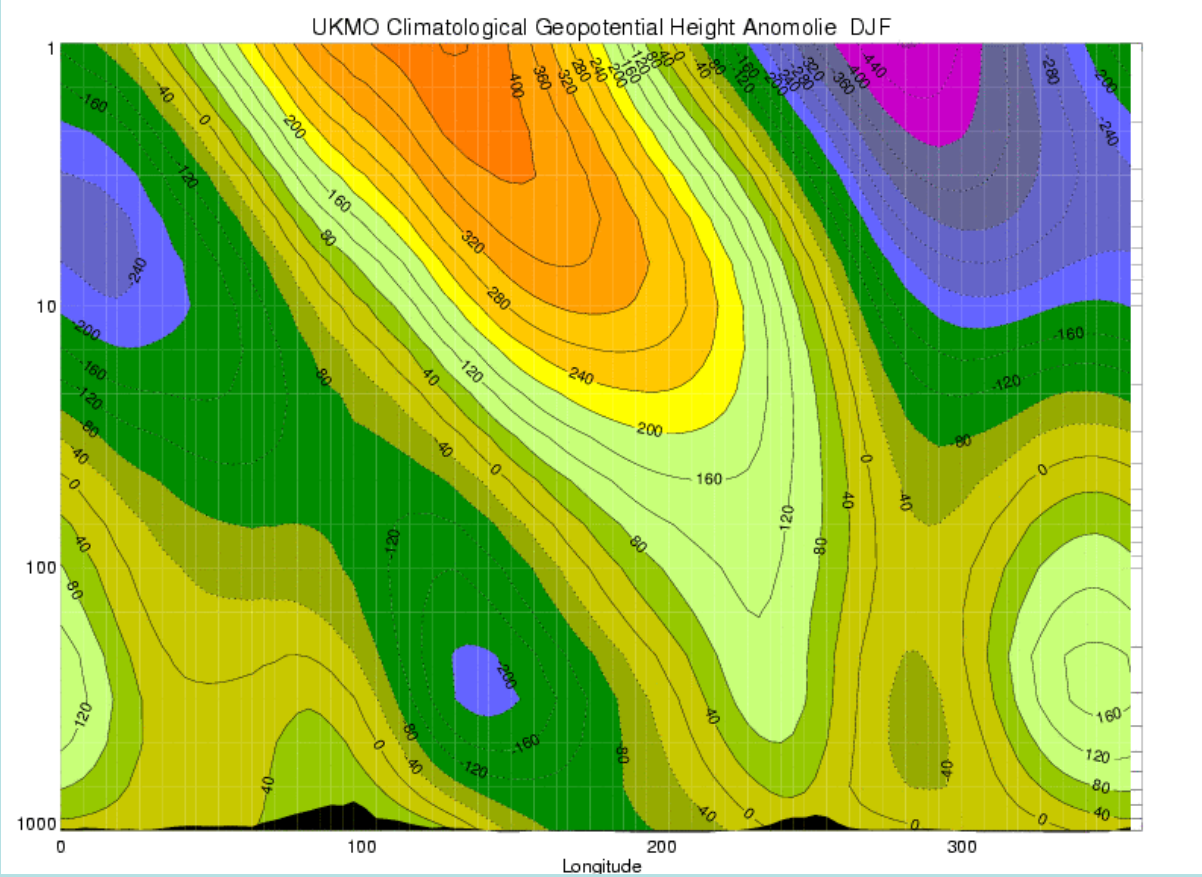
UKMO DJF 10mb Climatological Heights



The 500mb pressure surface is in the middle troposphere.
The 10mb pressure surface is in the middle stratosphere.

Vertical Structure 30-60N

P (mb)



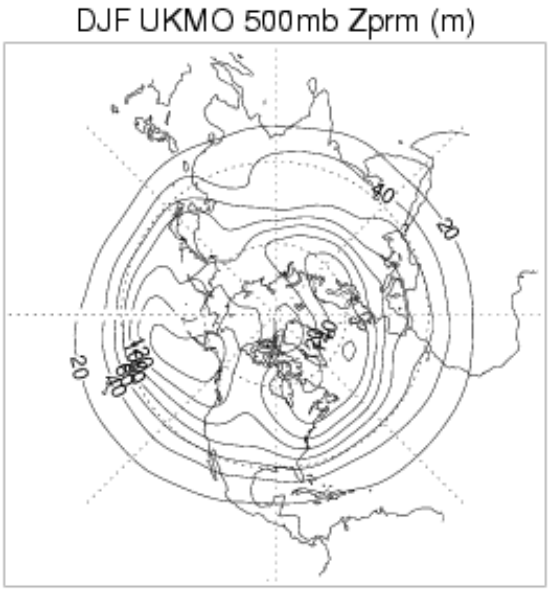
Longitude

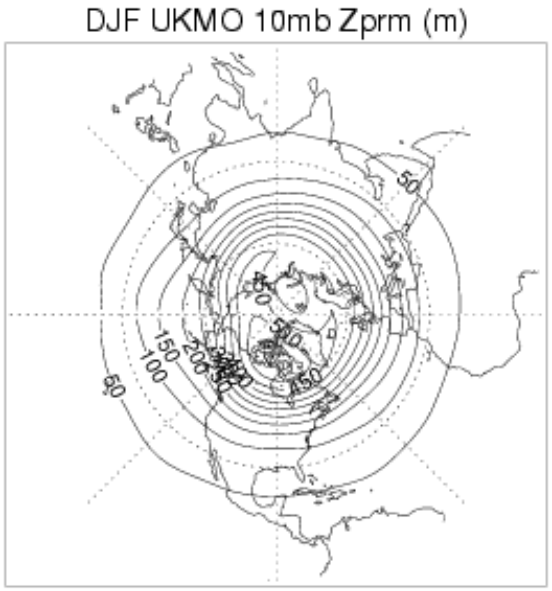
The phase and amplitude of the NH stationary wave pattern is analyzed by considering height anomalies (deviation from zonal mean) on a pressure surface.

NH Stationary wave theory

- The phase and amplitudes of the observed NH stationary waves can be described as an equilibrium response to orographic (mountain) and thermal (land-sea temperature contrasts) forcing.
- Charney and Drazin [1961] and Dickinson [1980] discuss continuously stratified planetary wave flow over topography.
- Vertical propagation of forced planetary waves is determined by a dynamical “index of refraction” which is determined by the vertical profile of the zonal mean wind.
- Westerlies promote the vertical propagation of long wavelengths while short wavelengths are damped.

NH Winter Transient Wave Patterns

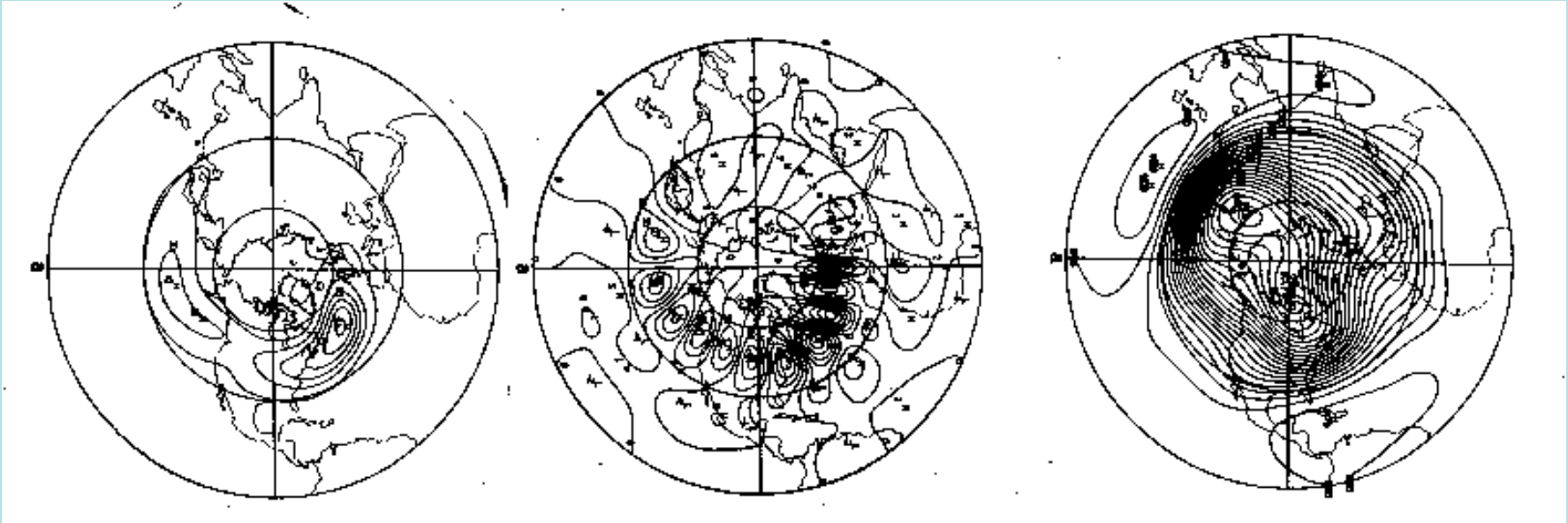




NH winter (DJF) transient waves are analyzed by considering the daily deviation (Zprm) from the seasonal mean height distribution on pressure surfaces in the troposphere (500mb) and stratosphere (10mb).

Unified 3D Instability Theory:

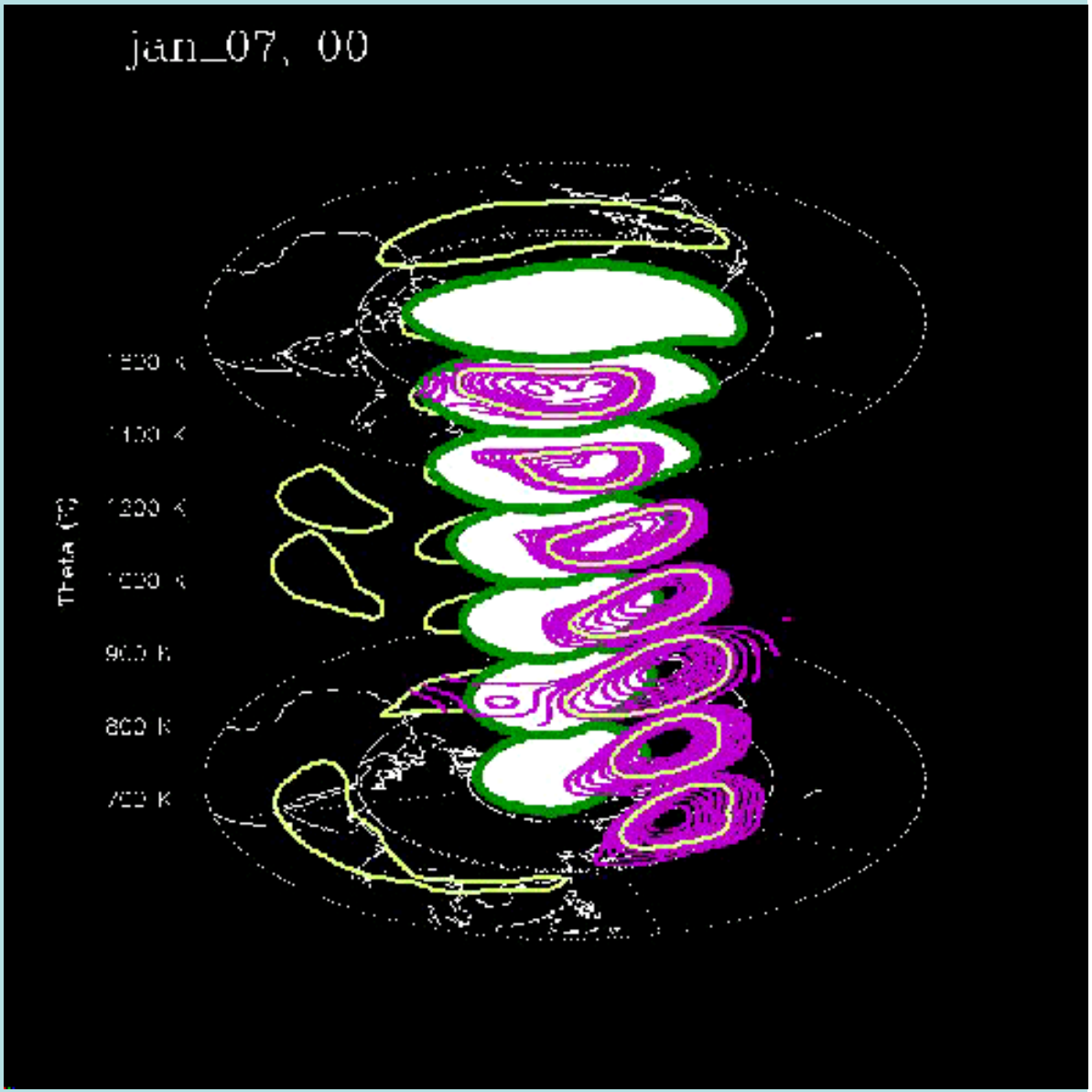
Frederiksen [1982]

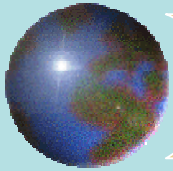


- Coupling between stationary planetary waves and baroclinically unstable waves (storms) leads to localized regions of cyclogenesis.

Stratospheric Transient Waves

The NH Stratospheric winter circulation pattern is characterized by the polar vortex (indicated in white) with mobile and quasi-stationary anticyclones. Stratospheric transport via these features has been found to be chaotic [Pierce and Fairlie, 1993]



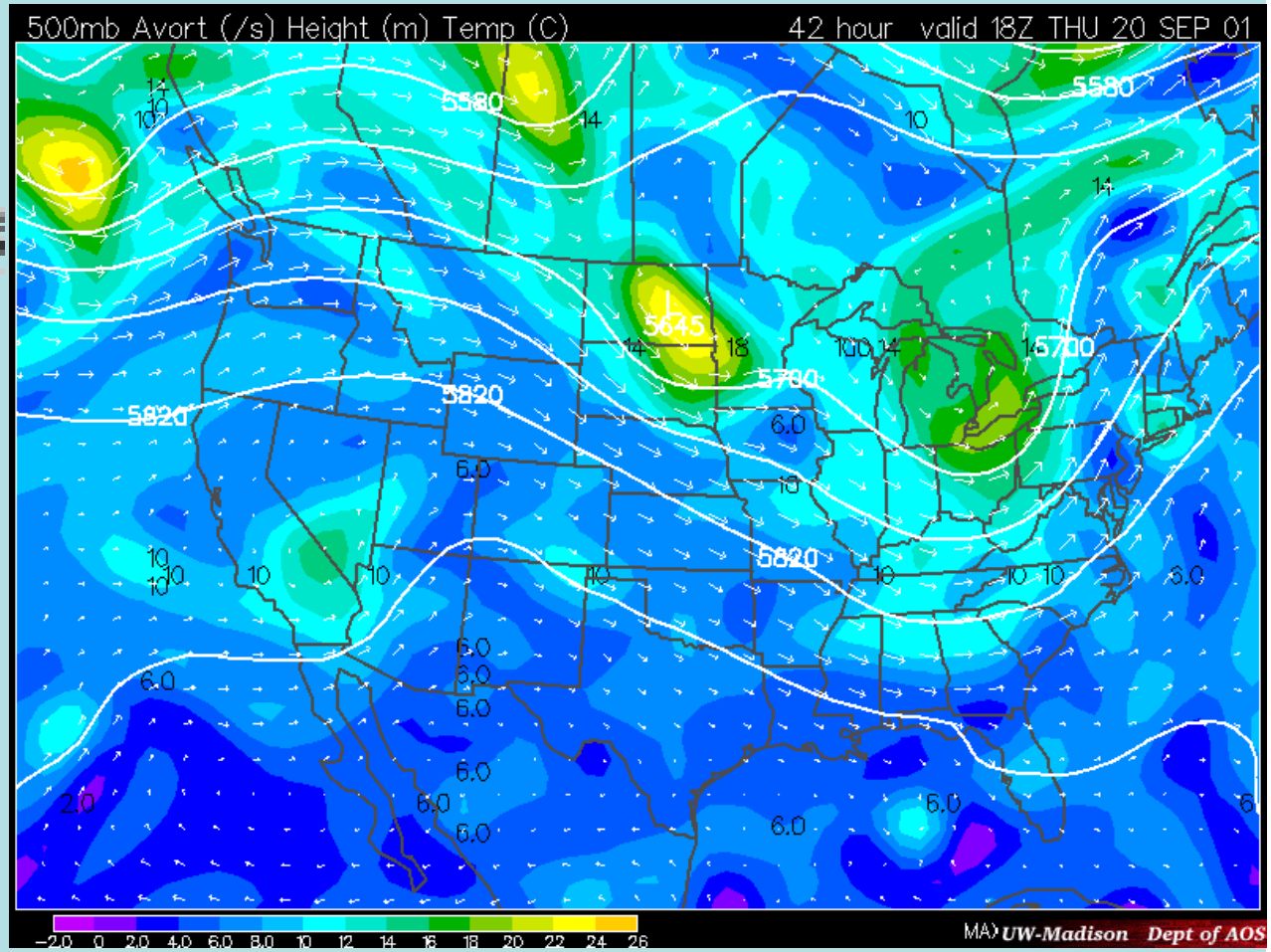


Applications of Dynamical Theory

- Numerical Weather Prediction
- Nonlinear dynamics introduces natural variability which can mask anthropogenic (manmade) atmospheric trends.
- Transport of atmospheric trace gases, and aerosols.

Numerical Weather Prediction

Today's 500mb forecast from the operational global aviation (AVN) model.

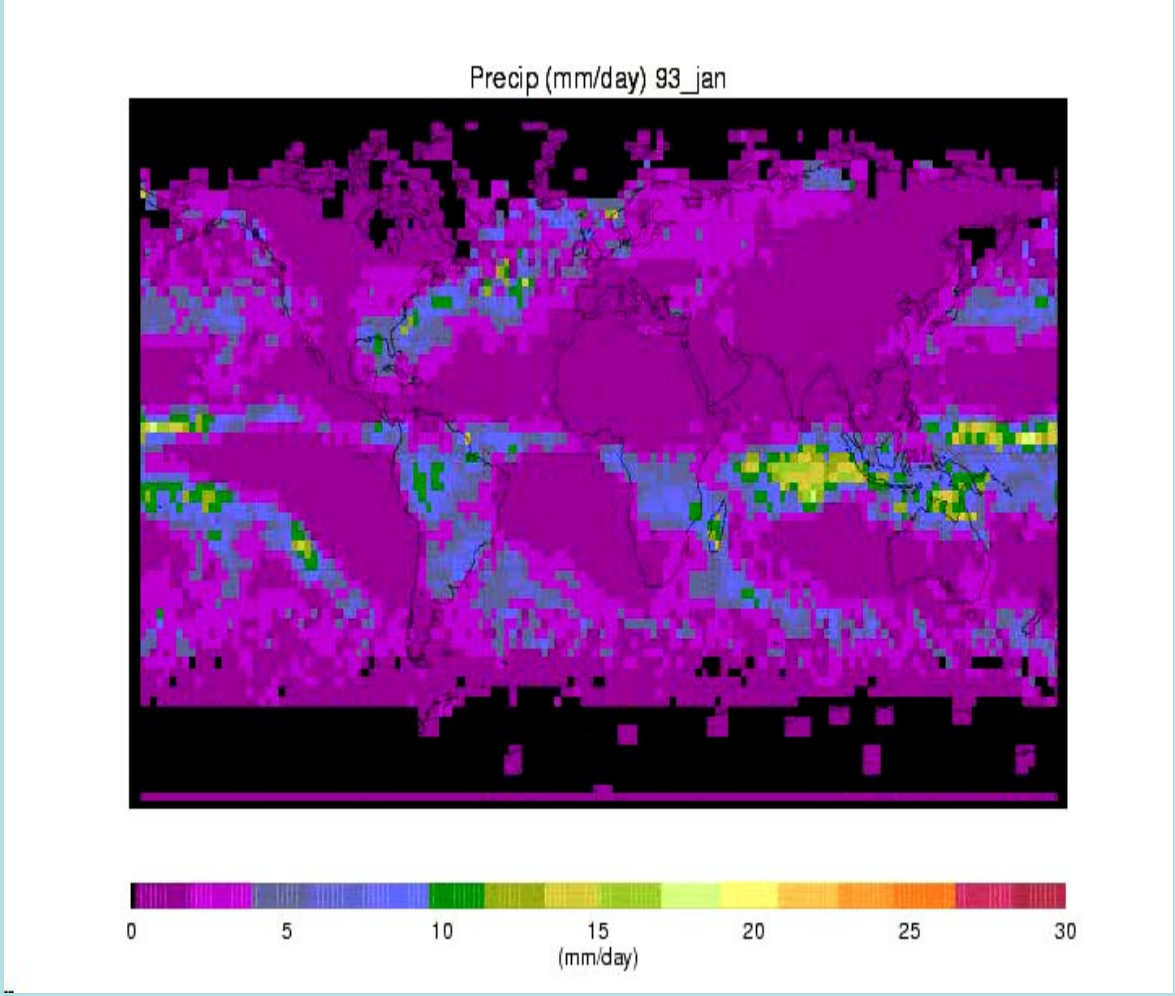


Natural Variability:

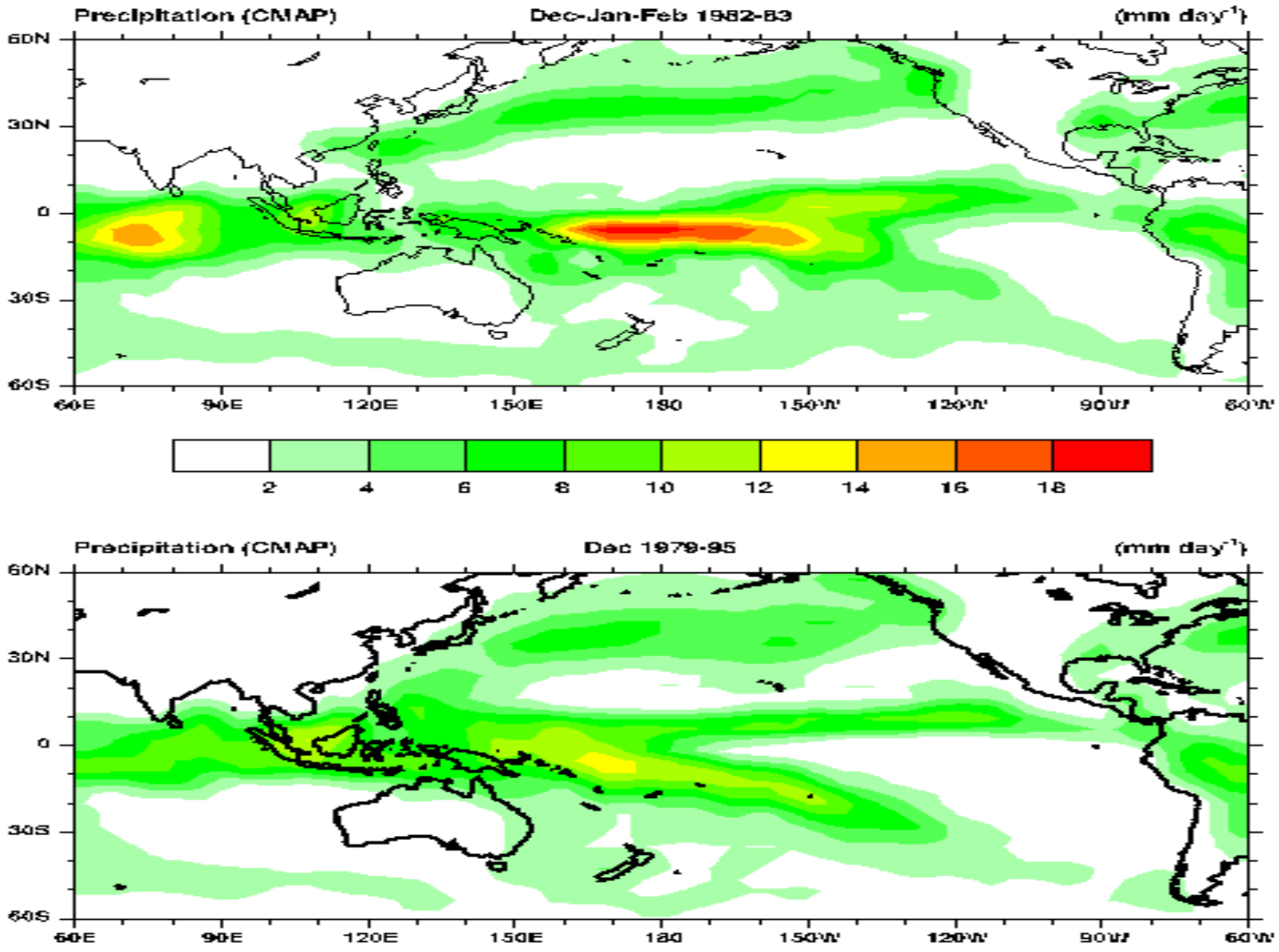
GPCP Monthly Mean Global Precipitation

The seasonal migration of the precipitation pattern is in response to changes in solar insolation.

The Asian monsoon season is evident as precipitation moves from land to ocean during seasonal cycle.

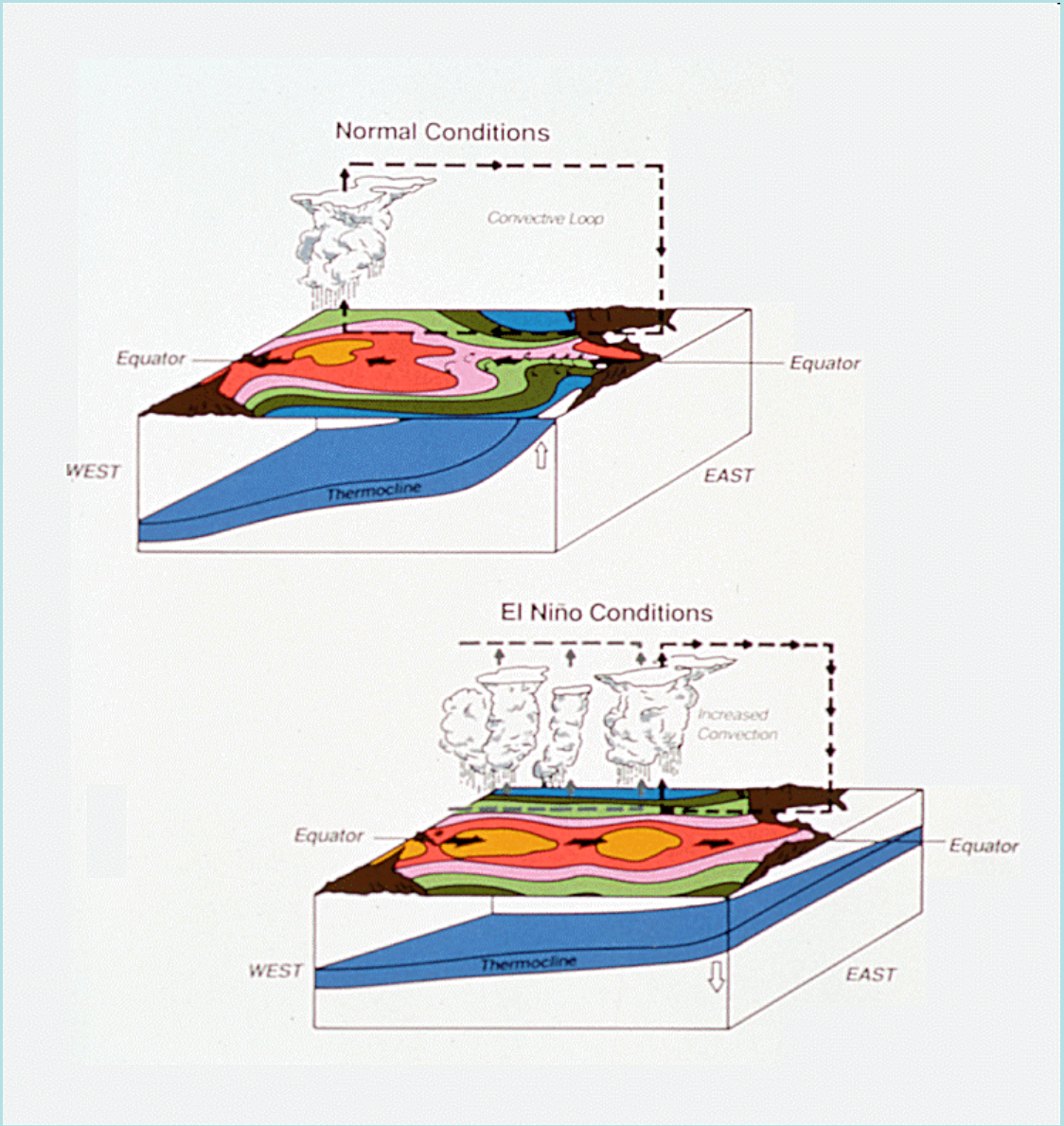


El Nino Precipitation Anomalies



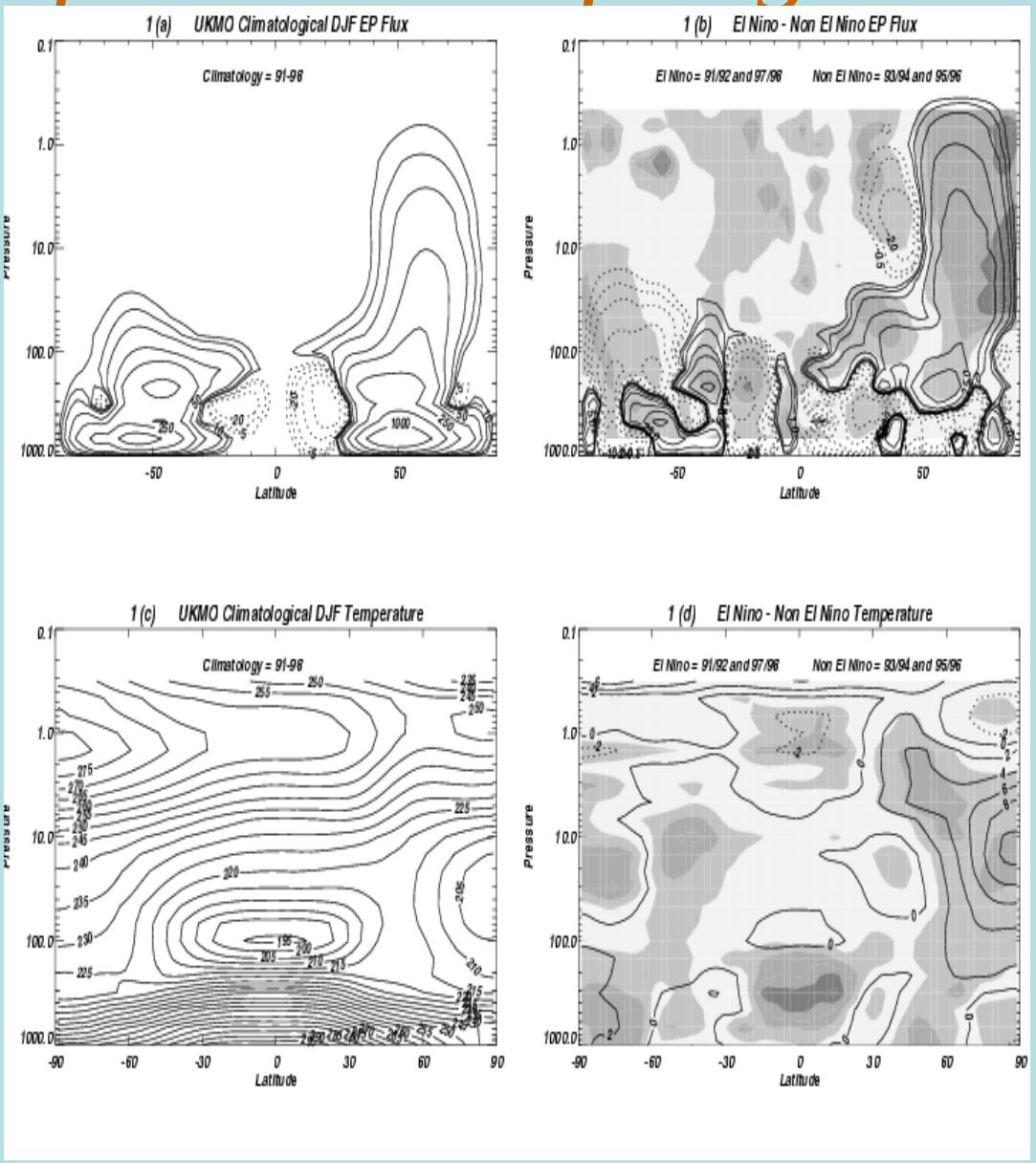
El Nino Mechanism

Decrease in the pressure gradient across the southern equatorial Pacific causes the winds to weaken . Warm water migrates eastward across the equatorial region. Rainfall follows the warm water eastward. The displacement of the latent/sensible heat source forces global circulation changes.



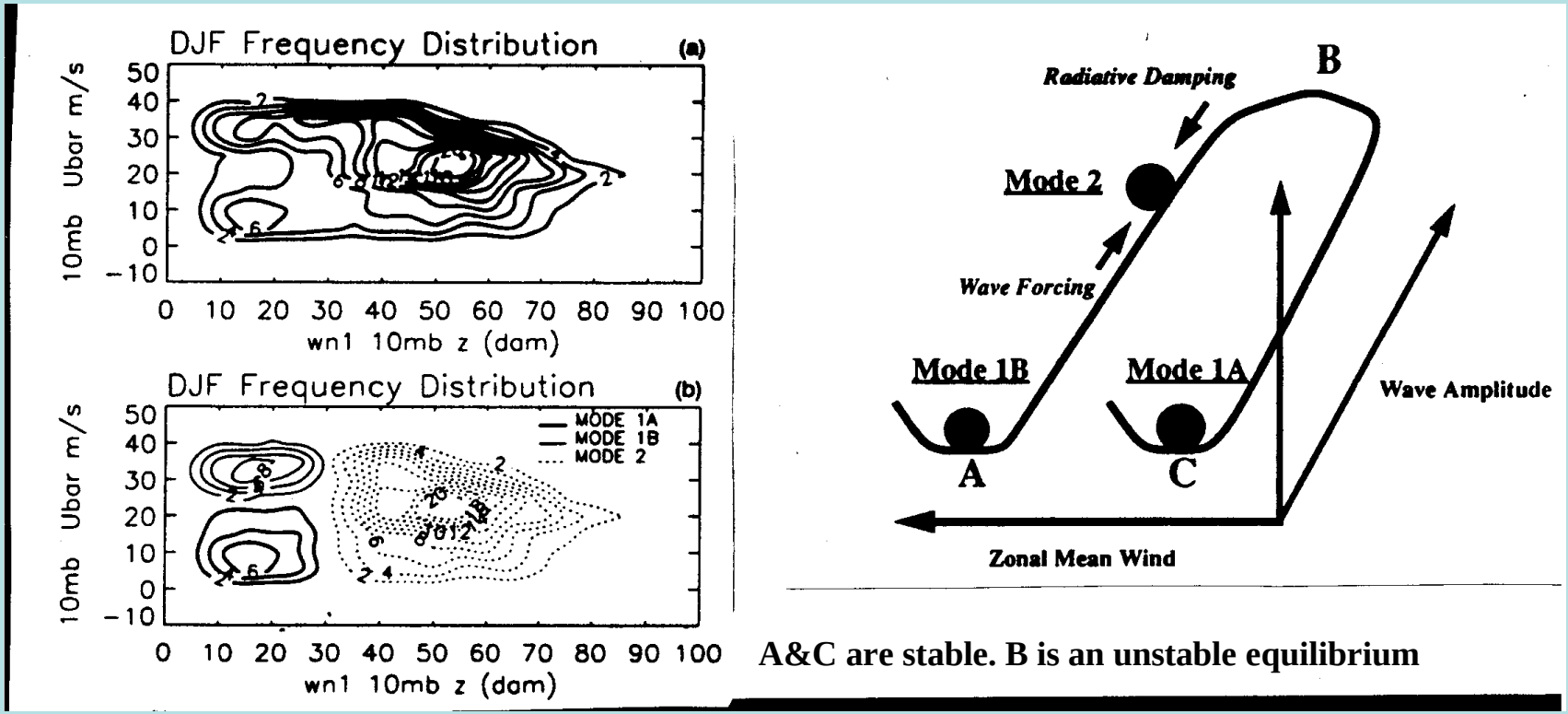
El Nino Trop-Strat Coupling

Analysis of the UKMO data at LaRC has shown that changes in the amplitude of planetary waves leads to increased fluxes of heat and momentum (EP fluxes) which strengthen the stratospheric meridional circulation. The stronger circulation results in warming at the NH pole do to compressional heating.



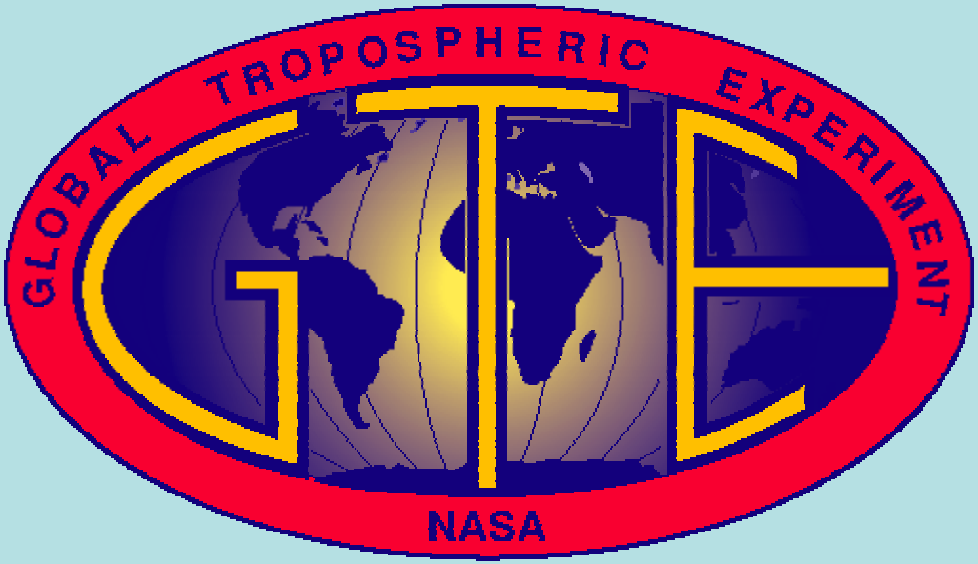
Preferred Stratospheric Flow Regimes

[Pierce and Fairlie, 1993]



The 2D frequency distribution of 10mb Ubar & Wave # 1 Z indicates multiple, preferred flow regimes. The maintenance of these multiple regimes can be interpreted as a consequence of multiple equilibria.

NASA TRACEP Mission

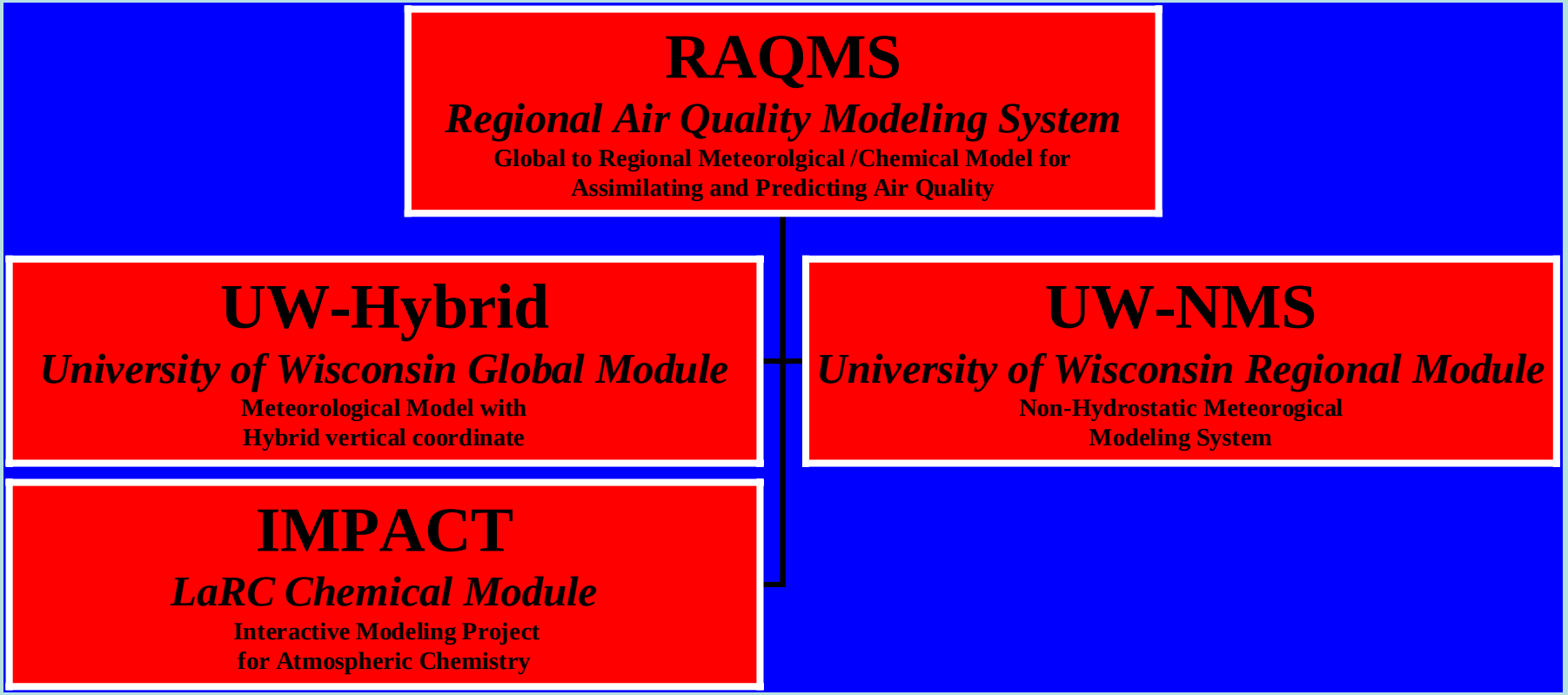


TRACEP (TRAnsport and Chemical Evolution over the Pacific) was an LaRC led NASA/GTE aircraft mission to E. Asia during spring 2001.

TRACEP was designed to:

- **Determine the pathways for outflow of chemically and radiatively important gases and aerosols, and their precursors, from eastern Asia to the western Pacific;**
- **Determine the chemical evolution of the Asian outflow over the western Pacific, and understand the ensemble of processes that control this evolution.**

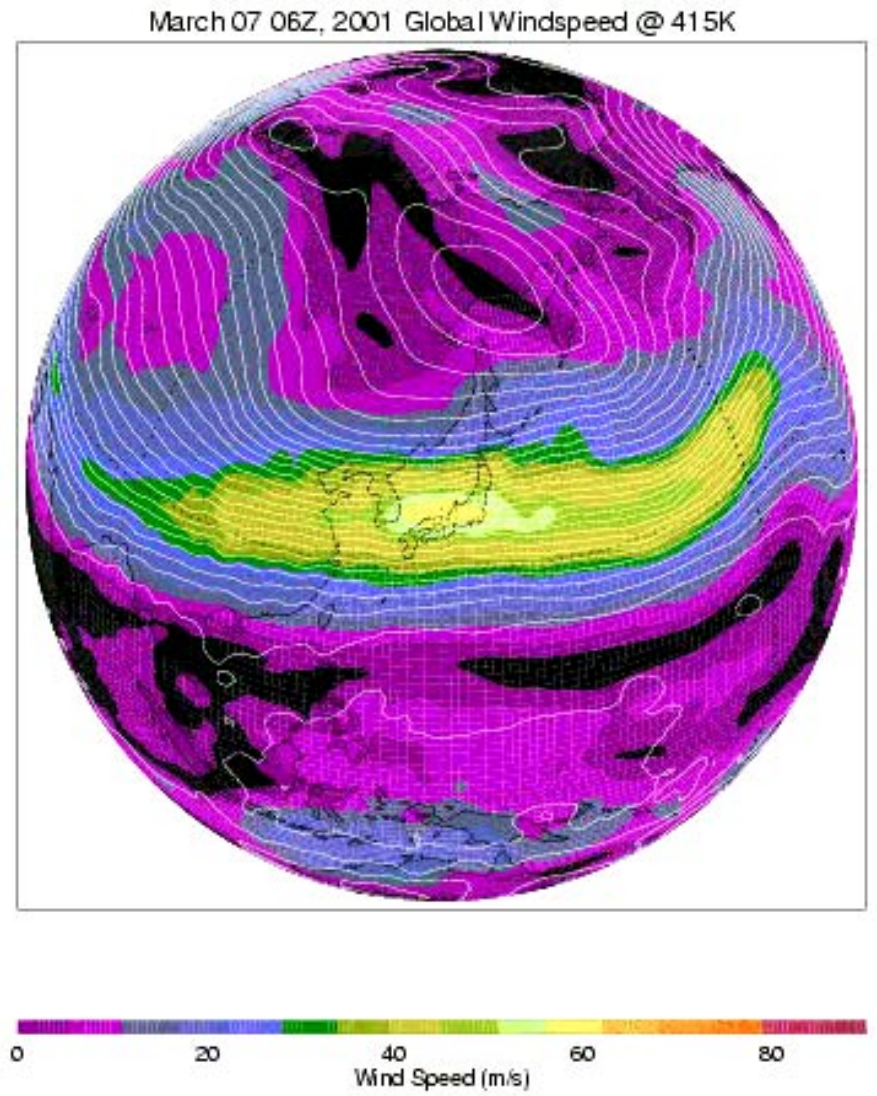
Regional Air Quality Modeling System (RAQMS)



RAQMS is a joint effort between LaRC and the University of Wisconsin-Madison (UW) to develop a meteorological and chemical modeling system for assimilating remote and in-situ chemical observations, and predict air quality within any region of planet Earth.

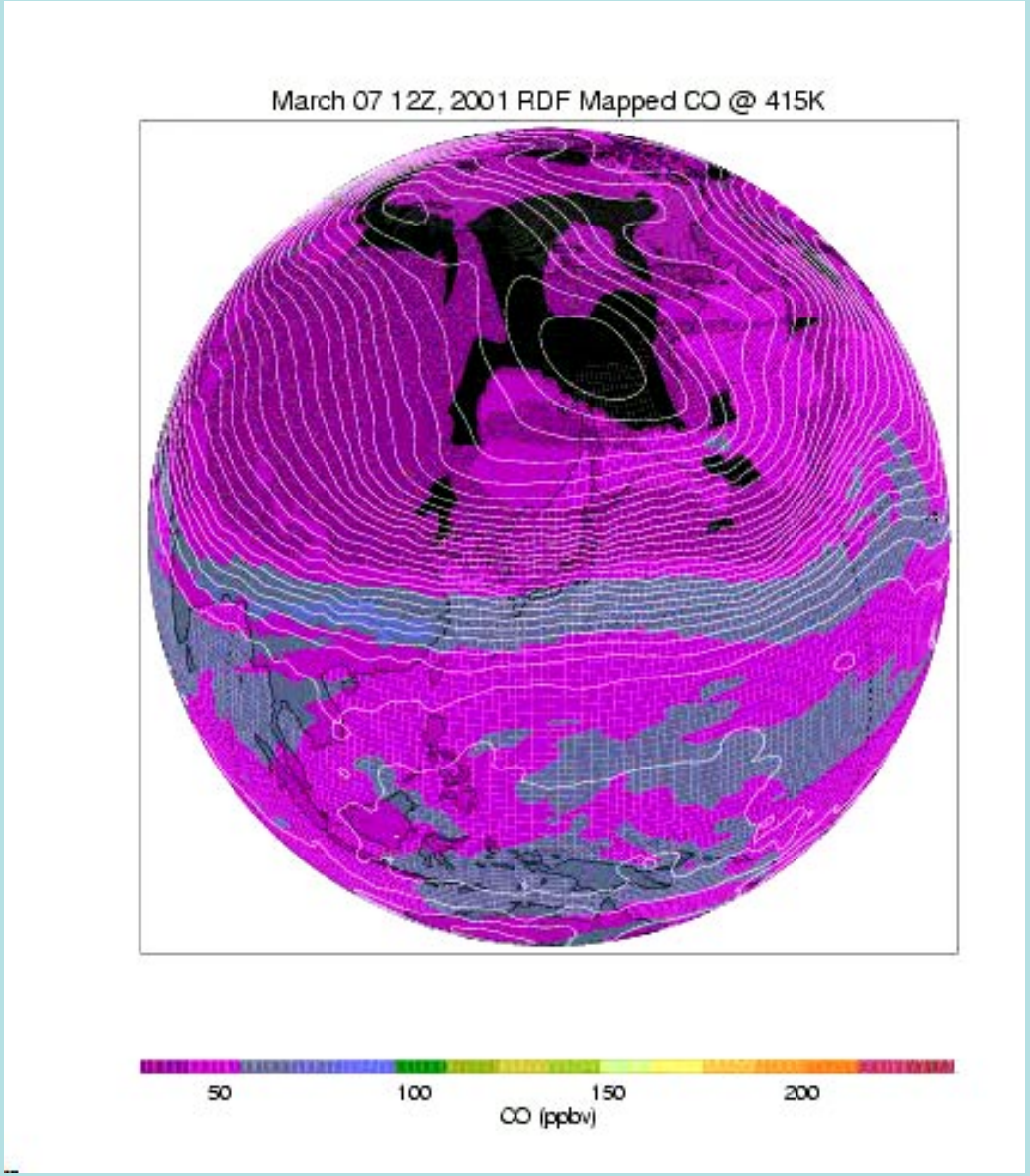
Dynamic Winds: A Global View

This movie illustrates the global distribution of winds (colored) and Montgomery Stream Function (equivalent to Heights) on isentropic surfaces during TRACEP.
The data for this isentropic analysis was obtained from the NOAA National Center For Environmental Prediction (NCEP)



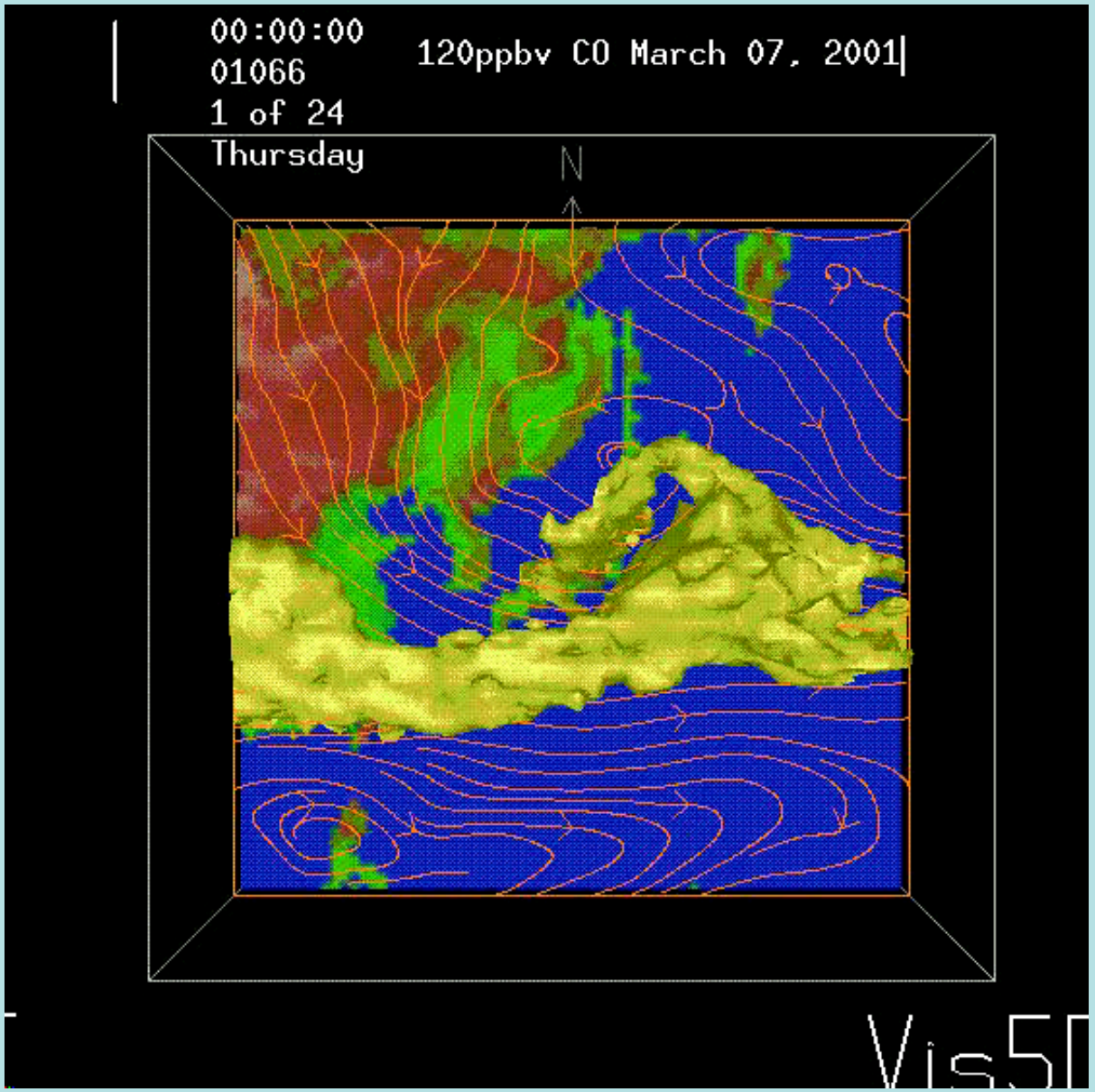
CO Transport: A Global View

This movie illustrates the global distribution of Carbon Monoxide or CO (colored) and Montgomery Stream Function on isentropic surfaces predicted by the LaRC TRACEP theory team. The CO prediction was obtained by mapping the LaRC IMPACT model CO climatology using Lagrangian mapping techniques.



CO Transport: A Regional View

This movie illustrates the regional distribution of Carbon Monoxide or CO (colored) Stream Function on isentropic surfaces predicted by the LaRC TRACEP theory team.
The CO prediction was obtained using the UW-NMS regional component of RAQMS.



CO Transport: Cloud-scale view

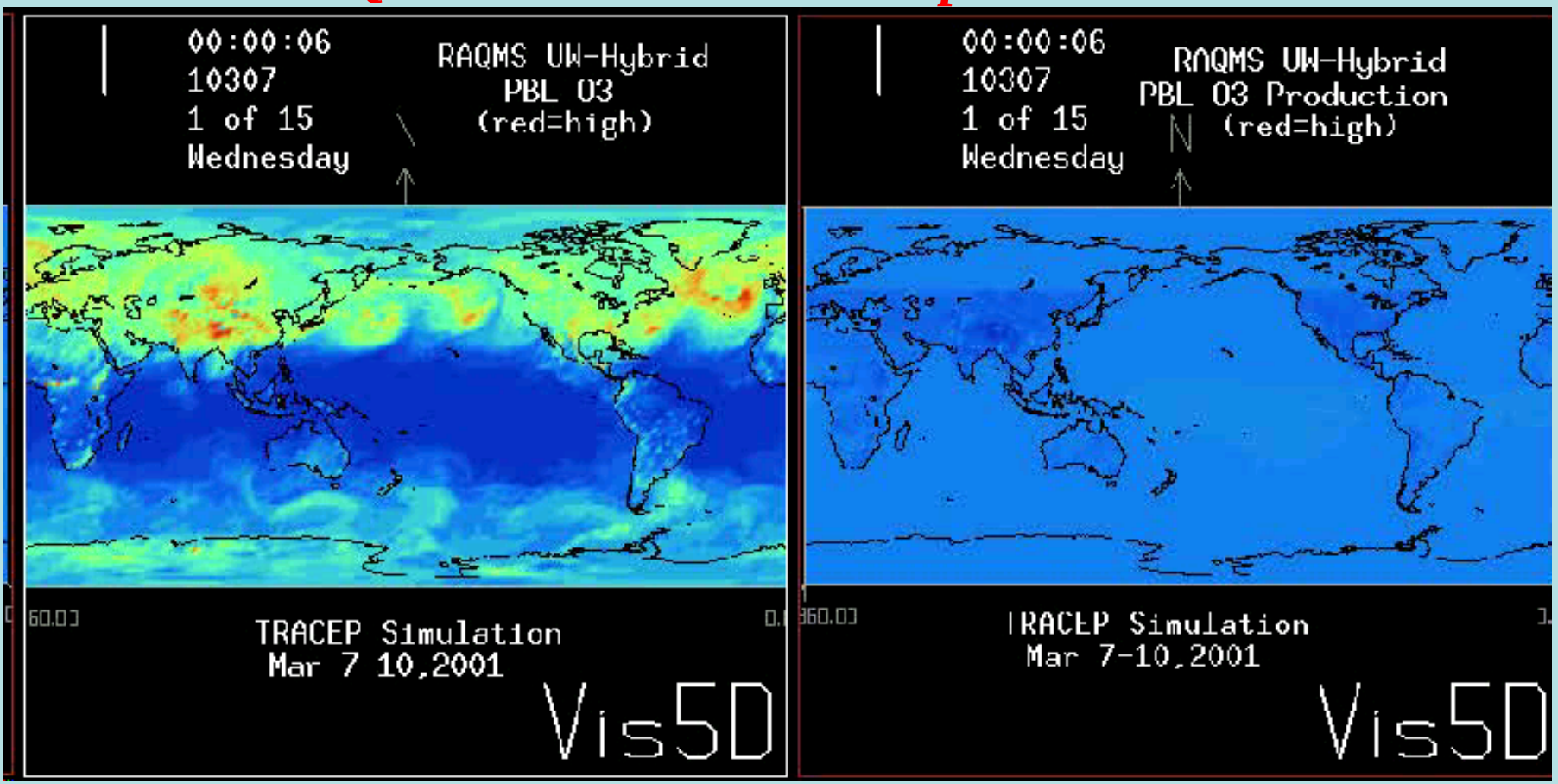
This movie illustrates the cloud-scale distribution of tracer transport predicted by the Wisconsin Dynamical/Microphysical Model (WISDYMM).

The scale of motion within the developing thunderstorm is less than 50km, which is the grid size of the regional component of RAQMS.

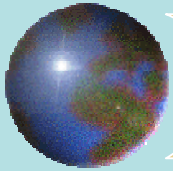
Isosurface (1.0 ng/g) and contour plot (0.5 ng/g) of tracer mixing ratio

Global Air Quality Prediction

RAQMS Global Ozone Transport&Production



This movie shows an ozone prediction (transport & photochemical production) from the UW-Hybrid global component of RAQMS.



Summary:

- Atmospheric Dynamics is the study of fluid dynamics (air) on a rotating sphere (Earth).
- Equatorial heating (solar/latent) and polar cooling (longwave) establishes a meridional temperature gradient which ultimately drives the Atmospheric circulation.

Summary (Cont):

- The observed NH stationary wave pattern can be understood as the quasi-equilibrium response to forcing at the earth's surface (orographic, thermal).
- Baroclinic instability about this stationary wave pattern accounts for much of the transient motion in middle latitudes and gives us our daily weather patterns.
- Due to the highly nonlinear nature of atmospheric dynamics, multiple flow regimes and decadal oscillations are observed. These internal oscillations complicate the interpretation of atmospheric trends.

Summary (Cont)

- At NASA LaRC most of our dynamical studies have focused on modeling and understanding the processes that are responsible for long term variations in stratospheric transport and chemistry.
- We are now collaborating with researchers at the University of Wisconsin to develop dynamical and chemical modeling systems designed to predict global and regional air quality.